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# Method and Device for Producing Dimensionally accurate Foam

The invention relates to a method for producing dimensionally accurate metal foam from foamable, powder-metallurgic semi-finished metal products having a melting point > 200øC, as well as to devices for carrying this out.

Production of foam from suitable foamable material for plastics, natural substances, glasses and also metal-containing materials, is known.

Methods for powder-metallurgic metal foam production in moulds having low expansion coefficient are known from DE 199 54 755 A1. There, powdermetallurgically AISi12 alloy is foamed up; however, the information given there is only suited for this material, as continuously material-dependent magnitudes are mentioned. This also holds good for the necessary 5 - 25 nm thick protection layer of the quartz glass mould by an Al2O3-coating of the quartz glass, as well as for the applied cover layer which is necessary on account of the reactivity of the foaming AISi12. There, also through a thick-walled mould with layer thicknesses >5mm and an applied protection layer is coupled radiation in mid-infrared, whereby the infrared emitter is geometrically arranged in such a way, that heat sinks occur in the powder compact. This known method can only work with powder compacts which are applied on cover layers and there occur problems with non-uniform heating of the mould, which results in non-uniform foam samples and foams which are not dimensionally accurate, which particularly in the case of larger foam parts, leads to instability of the foam and hence to cracks, weak points etc.

So far it has been extremely difficult to produce such metal foam parts which are dimensionally accurate in satisfactory quality. It is a problem to achieve a uniform pore distribution in larger components, e.g. large-surfaced ones like metal foam plates with a base area of 0.5 m2 and more. Such metal foam parts produced according to the known foaming methods often have regions, in which the pores are collapsed, and as a result we have larger hollow spaces which weaken the stability of the component. In case of parts with non-uniform thickness or such ones with regions of higher density, which occurs by inserting

more semi-finished products at pre-determined points, particularly very often defects occur. This is especially due to the fact that traditional moulds of metal have a high linear expansion coefficient and a high heat capacity. The expansion coefficient lead to the situation, that great dimension changes take place on cooling, which negatively influence the dimension-precision and the cooling behaviour of the metal foam. Known moulds or casting moulds require a lot of energy for heating, due to which the cooling takes a long time and results in long cycle periods in production. The cooling can also lead to material problems in metal foam, in case composites are supposed to be foamed and too long dwelling in a fluid condition leads to undesirable reactions or dissolutions, like de-mixing phenomena. A further problem is that in the known foam processes in furnaces, an uncontrolled heat distribution in the casting mould leads to uncontrolled foaming of the foamable material and hence one does not get a satisfactory pore distribution.

In other known methods the semi-finished product is heated up in metal casting moulds in a furnace to a temperature which lies clearly above the melting temperature of matrix metal of the semi-finished product. In order to achieve an adequate productivity of the process and above all good quality of the metal foam, the heating also takes place very rapidly, i.e. within a few minutes. On the other hand, a very specific heating of the foamable material is very necessary, as otherwise individual regions of the semi-finished product do not get foamed, whereas other regions get over heated and the foam cells there collapse. Therefore, the casting mould must be heated in a very short time - e.g. with the least possible temperature differences for plane metal foam of uniform thickness - , which is particularly difficult for larger moulds or casting moulds and metal foam parts. A big problem in this case is the large heat capacities of known casting moulds, which cannot be easily cooled rapidly and, on account of the high heat conducting capacity of the metal, do not allow locally differentiated heating.

The known method of foaming in metal moulds in the furnace was disadvantageous, because it was difficult to control, had to be often interrupted and, one could not run the process continuously. Finally, the energy costs were also quite high.

It is the problem of this invention to present a method which allows production of uniformly foamed foam parts, even such ones having larger overall dimensions.

This problem is solved by the invention by a method having the features of patent claim 1. It is further solved by the device according to the invention having the features listed in patent claim 10. Advantageous embodiments can be obtained from the dependant claims.

Reference to metal foam below also includes bodies which essentially consist of metal foam, and also having non-foamed reinforcing elements like wires, grids, plates or even threads, filaments, whiskers, fastening elements like bolt bushes, hollow bodies like nonfoamed pipes etc. These structural elements could be connected during foaming of metal foam by means of positive fit or even material-fit; in this way one can avoid later fastening steps like boring, slitting or other mechanical joining methods, or adhesion bonding, welding, soldering or such processes.

The invention particularly pertains to metal foams of metals or metal composites foamed thermally at high temperatures over 200øC, preferably over 300øC or even over 500øC with the help of foaming agents.

The foams can be used as solid but even light construction materials. Such light construction materials find application in the construction sector as cover elements, light-weight load-bearing elements; in motor vehicle technology, as well as. in aircraft-, automobile- and ship construction, or even as acustic isolation panels or protection panels against mechanical or thermal actions ( fire-preventing components).

By "non-uniform" one means the momentary distribution of radiation in the mould, as well as the time-related application of radiation, i.e. the irradiation of the mould with different irradiation intensity as well as the time-differentiated irradiation of particular mould regions. Surprisingly, in this way one can control the metal foam generation and avoid occurrence of gas occlusions.

By metal foam one means here a foamed product which has defined outer dimensions.

The method can be carried out in a very advantageous manner with foamable materials having a melting above 200øC, preferably above 300øC or even melting points above 500øC.

Because, in this case moulds or casting moulds having lower linear coefficients of expansion and lower heat capacity, as well as controlled foam generation is used, one can obtain an extremely dimensionally accurate metal foam part. Suitable mould materials are ceramic or glass-type materials or even composite materials like fibre-reinforced composites like fibre-reinforced ceramic, glass or carbon, which are highly heatpermeable and fulfil the requirements of low expansion coefficient with enhanced stability under pressure and tension. It is also possible to cool off the moulds very rapidly, as the low expansion coefficient prevents damages which could occur due to longer cooling process in case of traditional moulds.

The process can also be carried out continuously in a preferred embodiment which leads to a strand-type or band-type metal foam product. In this case, moulds open on both sides are used, whereby foamable material is introduced continuously into the mould/casting mould, which is irradiated in a controlled manner in a selected region and the foamable material is thus heated and foamed; whereby on the other side, depending on the mould or casting mould, the metal foam comes out foamed in the form of strands. Even here, the method can be supported by a separating material, in case the metal to be foamed adheres strongly to the mould - e.g. by letting foil-type separating material to run along, like $Al_2O_3$, or $ZrO_2$-containing foils or graphite foils for aluminium foaming, or by coating the foamable material with separating material foils, or by coating with a high temperature cinder base like silicate base; suitable separating agents are known to the expert.

The mould should preferably be at least partly diatherman. By diatherman one generally refers to material which is permeable for heat radiation, in this case radiation-permeable in the range of approx. 760 - 5000 nm. As suitable radiation source one could use those emitting continuously in the range of 760 - 5000 nm, or even selected wave length emitting emitters,

like pins, Nernst-pins, SIC-rods, LEDs, CO2 - CO-, diodes-, Nd/Yag-, semiconductor or colour lasers. Their energy output can be regulated by regulating the supply current or by using a filter.

The casting mould should preferably be thin-walled. This would be advantageous because one can avoid wastage of heat energy for heating up an casting mould having high heat capacity, and its cooling behaviour is faster - which prevents separation of composite foams, longer time cycles and allows precise controlling of the heat energy acting on the material to be foamed. It could, for example, have a wall thickness of 1 - 20 mm, more preferably a thickness of 2 - 10 mm. In case of thin mould walls, on account of heat management, it could be sensible to support them mechanically from outside, locally by supports or beams, in order to prevent bending or breaking of the mould in case of heavy metal foams or larger parts and to ensure retention of the dimensions. Suitable supports could be studs, or grid-type or honeycomb-like constructions, which would have as less support surface as possible and low heat conductivity and heat expansion coefficient and would consume less heat energy, in order not to disturb the heating profile. In case the studs can be regulated, it would be advantages to compensate for unevenness of the casting mould or the heat expansion of the supports themselves.

The casting mould can be fed with a suitable gas - even under over pressure. Ideally, an inert gas is used under not too high over pressure in the range of below approx. 5 bar. Thus one can conduct foaming of several non-precious metals or their alloys or composites, like Zn, Ni, Al, Mg, Ca, Ni, Fe, Sn.

Metal powder mixings can be carried out, or even mixings of precious metal, copper, beryllium, tungsten, titanium, steels, Si or their alloys, if required with additives, like hard substances, fibre and foaming agents for producing the metal foams, like hydride- or carbonate of metals - e.g. TiH2, ZnH2, MgH2, CaCO3 etc., as already known to experts in the field of metal foam production. One is particularly referring to substances releasing gases at higher temperatures, preferably such substances which are absorbed in the foam metal by formation of alloys after setting free the gas. Typical metal foam materials are ones which

have a large share of Al, Be, Mg, Si, Cu, Zn, Ti, Sn, Pb, lead, brass, bronze etc. With the help of the method as per the invention, one can also process fusion-metallurgical not producible alloys. Typical are titanium alloys, like TiAI, TiAlNb, certain magnesium or beryllium alloys, as known to the expert. One can also use composites like glasses. Typical oxidation-prone metal alloys are those of Mg, Ca, Al, Zn, Fe, Sn, but by no means restricted to these. Foaming under normal atmosphere is possible, but leads to thicker walls of the pores, larger pores and generally to lower achievable porosity than in the case of protecting atmosphere. The cost-effective variant of normal atmosphere, on account of saving expensive gases, should preferably be used in case of particularly oxidation-prone metals, like in the case of some Al-alloys. The foamable material could also be foamable plastic or foamable metal semi-finished product - like powder-metallurgic, cold-compacted, heat-compacted, or even extruded mixtures of metal powder with foaming agents, like metal hydrides, e.g. TiH2, ZrH22, MgH2 carbonates, nitrides, hydrocarbonates, or mixtures of oxides with carbon, as already known to the experts. These starting materials could also be introduced into the mould or casting mould together with reinforcement elements or structural elements, like hooks, bolt sleeves or such items, as well as reinforcement parts - nets, filaments, threads or even cover foils, in order to obtain a decorative or at the same time protective layer of the metal part, or to fix connecting components therein. The final spatial arrangement thereof reinforcing parts or layers can be ensured by providing consumable holding elements in the moulds. Preferably the casting mould - if it is closed - should be closable gas-tight and should have an overpressure valve, as well as a gas inlet and outlet.

It could however also be meaningful, in case a precise shaping of a surface is not necessary or desirable, that the casting mould is open at least from one side and foaming is carried out in the casting mould which is open on one side. The thus produced parts have an at least free-foamed, geometrically interesting surface, whereas the other surfaces are shaped dimensionally accurate.

It can be provided, that a controlled gas atmosphere is set and maintained in the casting mould. The closed casting mould should withstand gas pressure between 2 to 5 bar. During foaming, even a pressure change can be effected - in which case, if an abrupt reduction of gas

pressure is carried out in the foaming material, one gets production of metal foam with fine and more uniform pores. The atmosphere in the casting mould during the foaming process can be adjusted with respect to its composition as well as with respect to the pressure prevailing in the casting mould during foaming. Cost-effective air is suitable as gas - in case oxidation plays only a subordinate role - however, one can also work with inert gas or any other gas which does not react in any significant manner with the foaming material, e.g. nitrogen or argon. However, if a gas reaction with metal foam components is desired - e.g. formation of nitrides in metals - one could also use a suitable reacting gas.

In a preferred embodiment, the casting mould is at least partly diatherman and the content of the mould can be specifically locally heated by controlled radiation and foamed. For this, it would be suitable to use a laser with emission wave lengths in the range of around 3000 nrn or other suitable emitters of thermal radiation with a high share of radiation in the wave length range of approx. 760 - 5000 nm.

In special cases, it could be meaningful to cover the mould or casting mold material with a separating agent suited to the material to be foamed - this can be done either by coating the mould or by placing foils like fibre mats or material foils like metal foils. The separating material can also be directly applied in foil form on the foamable material. The separating agent is not always necessary, but prevents reactions between metal foam material and casting mould, produces a structural surface in case of smooth mould surface and can also allow relative movement of the metal foam against a mould, in case there is a separating foil.

It is particularly desired that the heat radiation is generated from controllable emitters, because in that case the foaming can be effected in a controlled manner and regions of the casting mould, which are supposed to produce a larger metal foam thickness, can be supplied accordingly with more heat energy. However, one could also use a single radiation source, like a laser, with a corresponding radiation splitting. The radiation emission of the emitter is monitored with the help of suitably arranged sensors and controlled according to the measured signals emitted by these. Thus one can set and carry out a pre-defined heating profile, in order to specifically control pores distribution and the foaming process. This is

particularly important in the production of products with non-uniform thickness or density, as a specific foaming front has to be reached in order to obtain a product with desired pores distribution, without undesirable gas occlusions.

If the process is to be carried out continuously, it could be advantageous if the casting mould is open on both sides and the foamable material is heated and expanded in a controlled manner in the open casting mould through radiation, while the foamable material is continuously introduced into the open mould - preferably with a separating foil.

Further objectives, features and advantages can be obtained by carefully considering the following description and the claims, along with the accompanying drawings. For more complete understanding of the nature and objectives of the invention, it is referred to the drawings. These show the following:

Fig. 1 A schematic representation of the process steps;
Fig. 2 A perspective part view of an arrangement for conducting the process as per the invention;
Fig. 3 A schematic view of the continuous process;
Fig. 4 A representation of foaming in open mould;
Fig. 5 A representation of a mould for producing angular elements.

Preferred embodiments of the nvention are described below on basis of production of metal foam plates; however, it is not restricted in any way to the special material or moulds mentioned there. According to this method, one can also similarly foam at high temperatures other meltable metals, like nickel, tin, aluminium, magnesium, silicium, titanium, metal alloys like bronze, glass or even glasses and thermoplastic plastics.

Examplray embodiments:

Example 1
Foaming of Zinc

Foamable, powder-metallurgically produced zinc semi-finished product 14 of a Zn alloy with 14wt.% of Al, 0.8 wt.% of ZrH2, 84.2 wt.% of Zn is produced through cold-compacting of powder material, and then introduced into a box mould 10 with over pressure valve, which is made of diatherman silicium ceramic with a linear expansion coefficient of 0.5 K-1 and which is sealable - as schematically shown in fig. 2 - and the cover of the box mould is closed in a gas-tight manner. The ceramic box mould is treated with separating agent before introducing the zinc semi-finished product.

The mould is subsequently evacuated, gassed with argon and an overpressure of 2 bar is set in the mould. Optically aligned radiation with an emission wave length maximum in the range of 3000 - 5000 nm is directed - according to a previously conducted pyrometer measurement of the radiation profile - on to the diatherman mould surfaces according to the pre-determined heating profile under foaming of the foamable material. After a predetermined time period, the heat radiation is switched off and the mould is cooled rapidly by means of air circulation with the help of a fan. The completely foamed zinc foam plate is removed from the mould. The thus produced plate revealed a very high mould loyalty and uniform foam quality.

Example 2

Foaming of Aluminium

Cold- or hot-compacted foamable powder-metallurgically produced material parts 14 made of AIMg0,6Si0,4 with 0.4% TiH2 are placed into a closable diatherman casting mould 10 made of Y2O3-ceramic having a quadratic base and wall thickness of 1 cm and an area of 1m x 1m and then it is closed. The lower surface of the mould is uniformly supported on its lower side by means of pin-like supports 18, in order to prevent deformation thereof while introducing heavy metal. Now thermal radiation from emitters 16 with an emission maximum in the range of over 3000 nm controlled over a sensor field - is uniformly directed on to the lower and upper surface of the mould, whereby the foamable material gets heated and foams up and fills the mould. The temperature of the material during foaming is approx. 600øC. Here the

mould or casting mould material is protected by a graphite-containing foil, which is applied before introducing the semi-finished product on to the mould or casting mould surfaces. The foaming takes place here without protective gas. The mould is then opened and the foamed aluminium foam plate is removed. The plate was dimensionally accurate and had uniform pore distribution.

Example 3

Foaming of Aluminium

The method was conducted as described in example 2, whereby the mould 10 was kept under an N2-overpressure of 2.5 bar during foaming. The thus obtained formed part had smaller pores and thinner pore walls. It was found that the size of the pores and wall thickness of the generated metal foam can be controlled through the mould inner pressure as well as the type of gas present during foaming.

Example 4

Production of an angular part

An angular mould, which at least partly is made of a diatherman ceramic material (see schematic depiction in fig. 4), is coated with carbon 12 and then foamable material 14 is introduced into it., The further process of foaming takes place as described in example 2.

Example 5

Foaming in open mould

A box-shaped mould, as shown in fig. 4, with a bottom surface made of diatherman ceramic, is uniformly heated with the help of a flatly arranged and controlled emitter 16 with an emission wave length maximum of 3050 nm. Cold-compacted semi-finished product parts 14 AISi10Mg1 with 0.4% TiH2 were placed on copper foil 12. One obtains a foam part with precise base and side areas comprising copper, whereas the surface made of aluminium alloy has geometrically freely foamed, optically appealing mould. Such parts are suitable, in cases

where a freely foamed surface of the finished component does not disturb or is even desired and the efforts of mould-closing can be avoided.

Example 6

Continuous process

An casting mould made of ceramic and open on both sides, with a expansion coefficient of 0.5 K-1 is continuously provided from one side with a separating agent foil covered foamable material 14 of an aluminium alloy with TiH2 as foaming agent. Against a predetermined surface of the casting mould 10, a non-uniform heat radiation is introduced in a controlled manner, and thus the foaming process is started and finished. The foamable metal now foams the space between the mould cover and the mould base, whereas the metal foam surface is always covered by the separating foil, in order to protect the mould from adhesion of the metal foam, cooled during transportation and leaves the mould on the other side. The continuously exiting foam product with separating foil coming out of the exit side is then further treated in a desired manner, e.g. cut by water jet, laser etc. or, if required, to the desired lengths. The mould or casting mould can then also itself be passed by a corresponding radiation field along with the material to be foamed.

Example 7

Mg-foam

An Mg-powder mixture with 9% Al, 1% Zn + 1% TiH2 was compacted cold-isostatically and then extruded at 400øC to long profiles of 20 x 5 mm. The thus produced foamable semi-finished product was placed into a closable two-part casting mould of graphite and heated in a water-cooled infrared furnace up to 650øC. The inner chamber of the infrared furnace and the casting mould was rinsed during heating with argon gas. The temperature of the casting mould was measured and controlled. The infrared radiation led to high heating velocities (up to approx. 15 K/sec.), whereby the foaming temperature of 650øC was not exceeded. After switching off the infrared heating, rapid cooling took place. The finished Mg-foam has excellent dimension-precision and uniform and fine-pored structure.

Obviously the invention is not restricted to exact the design or composition of the examples listed or described; various changes or deviations from the core and protection scope of the invention are possible, which are known to the experts.

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